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Cutting wheat on the contour. See page 11.

CLIMATIC CONDITIONS AND SUGGESTED CROPPING SYSTEMS FOR NORTHWESTERN OKLAHOMA

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SUMMARY

To maintain a civilization in the High Plains, man must discover a system of farming which will be stable through periods of drought as well as through periods of abundant rainfall. This circular represents an effort to outline a system of farming which is adapted to climatic conditions in northwestern Oklahoma, so that farmers who follow it may have some assurance of a continuous existence in the area.

From a summary of previous investigations of crop, climate and soil relationships in the Plains region, it appears that available moisture rather than available plant nutrients is the limiting factor in the production of crops. Within limits, man can control the amount of moisture available for plant growth by adapting his cultural practices to the prevailing climatic conditions. Terracing increases grain yields, even on land which is almost level, by holding the moisture where it falls.

In addition to conserving moisture, man can also adapt his cropping system to the moisture available in any particular year. Crop rotations in dry-land farming must be aimed primarily at using crops which (1) are adapted to the soil-moisture available in a particular season and (2) will maintain a vegetative cover to prevent wind erosion. The effect of the crop on soil fertility is a secondary consideration.

To maintain a sufficient cash income, wheat must be planted as often as conditions promise a successful crop. It appears probable that rainfall data and the amount of raw crop residues in the soil can be used to give a fairly dependable forecast of the probable success of a wheat crop. The cropping system suggested is based on the substitution for wheat of some crop having more chance of success in those years when wheat does not have a favorable prospect. Some livestock would be kept to make use of the sorghum forage produced in such years.

Appendices present the data on rainfall, evaporation, and wheat yields on which the proposed cropping system is based.

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CLIMATIC CONDITIONS AND SUGGESTED CROPPING SYSTEMS FOR NORTHWESTERN OKLAHOMA

Harley A. Daniel and H. H. Finnell*

INTRODUCTION: PRESENT CONDITIONS IN THE AREA

The great dictator in the High Plains is Nature. Man, in order to keep a viable, healthy, and permanent civilization in this region, must discover a system of farming which is so adapted to Nature as to maintain a productive soil. In the development of a permanent civilization in the High Plains, the type of agriculture must be stable through droughts as well as during periods of abundant precipitation.

Meterorlogical records show that three major drought periods have occurred in the High Plains area since 1868. Tree ring and lake bed studies indicate that there were three periodic droughts long before this date.[29] Kincer[27] reports that a short succession of drought years like 1930, 1934, and 1936 does not happen very often, but that a similar condition occurred about forty years ago. He also believes that weather conditions recur in some definite pattern, and that therefore there will be more groups of wet and dry years in the High Plains region. If this information is correct, it is probable that droughts and the attendant liability of dust storms will always continue to visit the area, since high wind velocities and periodic low rainfall are characteristic.

During previous droughts, most of the land was in native grass and, based on recent studies by Murphy,[34] apparently contained sufficient vegetation and organic matter to aid in absorbing rainfall and preventing runoff. But, during the post-war period, a vast acreage of inferior land in this area was brought into cultivation, and in many instances this occurred coincidently with a period of ample rainfall.[4, 27] Tillage and cropping methods for this new country were not well understood, and practices developed that favored soil blowing. Then, suddenly, following a period of more than normal rainfall, came the most extended drought in recent history. This, combined with unwise tillage, caused soil movement on a large scale. The majority of the land affected by wind erosion at present is either cultivated or badly over-grazed. Many of these areas are either covered with hummocks or blown out to the subsoil (Figures 1 and 2), and therefore in ideal condition for the water to run off.[9] Calculations based on the estimated wheat yields from 1924 to 1936, inclusive, in Cimarron, Texas and Beaver counties show that the average percentage of the planted acres harvested was only 46.0, 61.6 and 63.1, respectively.[1]

In view of the foregoing, and of present unfavorable conditions for plant development in the Panhandle of Oklahoma,[9, 29] as well as of the high evaporation-rainfall ratios (See Appendix B), it seems certain that if a permanent type of agriculture is ever to be established on cultivated land where the rainfall is low, a revolutionary change in methods of water conservation and in crop management practices is required. While it would not be feasible to put the entire region back to grass, regrassing of all in-

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Figure 1. The effect of wind erosion in Cimarron County, Oklahoma.

ferior soil types is essential in order to control soil drifting and to make the most economical use of the land. Then, with a more intelligent land-use program in the rest of the area, and a better adaptation of crops to the other soils, the present erosion-control methods[4, 8, 20] will be more effective.

CONDITIONS AFFECTING CROPPING SYSTEMS IN NORTHWESTERN OKLAHOMA

Soils in northwestern Oklahoma have developed under the influence of a semi-arid climate. The availability of plant nutrients is therefore unusually high, due to the absence of leaching by rainfall; and it appears that available moisture, rather than available plant nutrients, is the limiting factor in the production of crops. The amount of water available for plant growth is, in general, subject to two classes of conditions: climatic and cultural. Climate cannot be controlled by man; but, within limits, he can control the amount of moisture available for plant growth by adapting his cultural practices to the prevailing climatic conditions. The amount of rainfall required by crops in different localities varies according to several modifying influences, with wide geographic variation. Among these modifying influences are temperature, wind, rate of evaporation, distribution of rainfall, and the moisture-retaining qualities of the soil. The latter influence can, to some extent at least, be modified by man. He can control the others only by adapting his cropping practices to them.

Climatic Conditions

Climatic conditions as related to plant development in the Southern Great Plains region, of which northwestern Oklahoma is a part, have been the subject of numerous investigations.

Finnell[10] evaluated seasonal variations and limitations in relation to efficient utilization of moisture and recommended precautions to be taken in order to avoid crop failure. He found that individual crop problems

may require more or less specific treatment. For example, best results were secured from row crops when planted so that they would mature just before frost, because the period of minimum wind velocity and maximum rainfall in the High Plains occurs in the summer months. (See Appendix B).

Metzger[33] reports that low rainfall brought about a high variability in the crop-producing power of soil under Kansas conditions.

Daniel[7] compared seasonal evaporation with plant growth and found that high evaporation was associated with low crop yields.

Finnell[10] and Thompson[41] have shown that crops are often influenced by the combined effects of high wind, high temperature, and low humidity.

Methods of Adjusting Cropping Systems to Climatic Conditions

In adapting cropping systems to climatic conditions in northwestern Oklahoma, there are three major factors to be considered: retention of moisture; prevention of wind erosion; and the crops used in rotations.

Holding Moisture. Since under ordinary farming conditions only about one-fifth of the total rainfall received in the Panhandle of Oklahoma enters the subsoil and is available for plant production,[13] there is apparently much room for improving the efficiency of moisture-retaining and moisture-using methods on the farms. Although a large amount of the land in the High Plains is almost level, conservation of water has been found to be an important factor in successful crop production on fertile land. At Goodwell, Oklahoma, on Richfield silt loam with a slope of less than 1 percent, the average annual grain yields of wheat and milo for a 10-year period were increased 3.1 bushels per acre by terracing and holding the water where it fell.[8] On the same soil type, terracing and contour cultivation increased the yield of Tepary bean hay an average each year of 273 pounds per acre for the years 1934 and 1937 inclusive, which were some of the driest seasons on record at Goodwell. Harper[21] reports that moisture

Figure 2. Productive wheat land blown out to the subsoil in west Texas County, Okahoma.

Figure 3. Sorghum making about 300 bundles per acre on the Soil Conservation Project near Conlen, Texas, in 1937. The south part of this 320-acre field made 1670 pounds of headed Hegari and 1560 pounds of milo per acre. A good stubble is left which will prevent wind erosion on a large scale if pasturing is prohibited.

saved by contour farming increased the yield of kafir and seed cotton at Granite, Oklahoma, during the season of 1935.

Initial soil moisture or the depth of wet soil at seeding time has been found[12] [22] [30] to be a very important factor in crop production in the Great Plains. (See appendix A.) Results[31] have shown that tillage of small grain stubble immediately after harvest is highly effective because it helps the soil to absorb and store the rains that fall after harvest.

Preventing Wind Erosion. In areas of severe wind erosion, raw organic matter, particularly in the form of crop residues, is also an essential factor in successful crop production. These residues influence the physical properties of the soil itself; and, if sufficient quantities are present, they also have a mechanical effect in controlling soil blowing,[6] [20] providing decomposition has not occurred to such an extent that the organic matter has lost its identity in the soil. General observations and measurements of dust in the air following rains[28] show that land without ample crop residues on or near the surface often drifts and destroys growing plants even though the soil is wet. Soil blowing does not occur, however, when the surface is protected with either established growing vegetation or by an adequate cover of undecayed crop residues. Native grass land seldom blows and never drifts unless badly overgrazed or located adjacent to cultivated fields where shifting soil has blown across or covered the sod and destroyed the grass. Crop residues, either as standing stubble (Figure 3) or when partly covered with surface soil as a result of tillage (Figure 4) are effective.

Experiments conducted at the Panhandle Agricultural Experiment Station[14] showed that crop residues were completely decayed after a period of three or four years on land continually fallowed. Because climatic conditions have been unfavorable for crop production since 1933, a fallow ef-

fect has occurred on a large amount of the land in the wind-eroded area; and as a result most of the valuable crop residues have disappeared.

Selecting Crop Rotations. As stated by Mathews and Cole,[31] crop rotations used in dry-land farming are basically different from those used in more humid areas. The maintenance of soil fertility is important, but not nearly so immediately important as other factors. In selecting crops to be placed in a rotation, stress must be placed on their soil-moisture relations and their value in maintaining a vegetative cover at those critical periods of the year when erosion is most severe, rather than on their effect on soil fertility.

As a general rule, the nitrates accumulated during seedbed preparation and during the period of moisture conservation are sufficient to produce as large a crop as the moisture is capable of maturing. In a demonstration at Goodwell, Oklahoma, the addition of nitrogen, either as commercial fertilizer or manure, often stimulated a vigorous early growth, but the results were frequently disastrous because moisture was incapable of maintaining such a high straw growth to maturity. Mathews and Cole state that "at Woodward, Oklahoma, on a sandy soil probably as low in nitrogen as at any field station in the Great Plains, it was found that manure increased straw growth materially, but that crops fired more quickly in dry years." They also reported results of similar experiments at Ardmore, S. Dak., and at North Platte, Neb., where the manure generally increased the growth of straw and decreased grain yields. In some years of high precipitation at these stations, the grain yields were increased by manure; but as a whole, instead of stabilizing yields, it made them more erratic.

Figure 4. Disking wheat stubble after harvest to destroy weed growth and put the soil in condition to absorb moisture on the Soil Conservation Project near Liberal, Kansas. The partly covered residue as left by shallow cultivation is very effective for controlling wind erosion. Note terraces and summer fallow strip in right background.

Economic Factors

Winter wheat is a comparatively sure crop in central Kansas[31] and in northwestern Oklahoma.[36] [37] On soils suited to its production, the cash return from wheat is so much greater than from other crops that the proportion of the farm land devoted to its production exceeds the amount for all other crops combined. A 10-year history of wheat farming in Garfield County, Oklahoma,[37] shows that more than 75 percent of the cropped land should be in wheat to secure the most satisfactory returns over a period of years. Other studies of farm management in this particular county[35] indicate that it is not so much a question of diversification versus specialization as it is the degree to which diversification can be practiced. Nelson, the author of these studies, also states that the "hazards incident to specialized livestock production in this area seem to be as high or even higher than those incident to wheat production."

In those sections of the Panhandle or High Plains where wind erosion is most severe, however, conditions are considerably different from those existing in the rest of the wheat area of northwestern Oklahoma. With frequent crop failures occurring even on the more favorable soils, it appears that a farmer in those sections must have some additional resources for existence. What must be done to establish a farming system that will permit the operator to carry on during the years of failure has been determined chiefly from observation. According to Mathews and Brown,[30] greater attention should be given to the production of forage crops as a means of supplying feed for small herds of livestock and flocks of poultry in furnishing a living for the family. The production of livestock provides a means for utilizing sorghum, but it also necessitates maintaining pasture and reserve feed. It seems feasible to store sufficient feed to maintain small herds through drought periods, but to avoid stress with large herds under several years of continuous crop failure is out of the question. One outstanding fact reported from the farm management study of Garfield County[37] was that the most successful farm was a wheat farm supplemented with livestock enterprises sufficiently large to prevent complete dependence upon wheat. It was also reported that the number of animal units on 100 acres of farm land in this particular county should range from about five to eight for most desirable results, except under somewhat exceptional circumstances.

TESTS OF CROPPING SYSTEMS

Experiments conducted by Finnell[16] [17] [18] [19] have shown that a flexible system of farming is the most practical for the wind-eroded area. This system was followed through a 10-year period at Goodwell, Oklahoma, and during this time the land was in wheat 40 percent of the time, fallow 20 percent and milo 40 percent. This experiment was conducted without water conservation methods, and, consequently, did not afford as many favorable opportunities for sowing wheat as would have been presented on another experiment running through this period of time on terraced land. These conservation practices (Figures 5 and 6) are very essential and pay good dividends on deep fertile soil;[8] but calculations show that about 18 to 20 inches of annual rainfall, with approximately two-thirds of it falling during the summer months preceding seeding time, is necessary before chances are favorable, as far as moisture is concerned, for a profitable wheat crop in northwestern Oklahoma. (See Appendix A.) Therefore, it appears that rainfall must be above the average to produce a good wheat crop in the Panhandle of Oklahoma. This information is also in agreement with that reported by Finnell[17] on the relative yield and dependability of different crops on Richfield silt loam soil. He found that the rank of crops was in the following order as to relative dependability: (1) sorghums for forage, (2) grain sorghums, (3) annual legumes (Tepary beans), and

Figure 5. Contour furrows holding water after a rain at Goodwell, Okla.

(4) wheat. Precipitation alone was found to be,[7, 30] a good basis for estimating sorghum yields. This crop is harvested in the fall, and the loss of water by evaporation during the period between harvesting and seeding is a much smaller factor than with wheat.

SUGGESTED CROPPING SYSTEMS

From a detailed study of all available information, it has been recommended[32] that wheat should follow wheat on the medium- and fine-textured soils in the wind-eroded area when moisture conditions are favorable and sufficient organic residues are present in the soil to prevent wind erosion. Owing to the importance of moisture for crop production in the High Plains, the cultivation and cropping systems on all land should be such as to conserve, uniformly distribute, and economically use the rainfall (See the cover* and Figure 7) to produce crops and maintain a protective cover. Continuous wheat, although it may be planted in alternate strips with fallow, affords much protection for the surface soil, because with proper management the land is covered with either the crop or stubble most of the year. There is little danger of the soil blowing on a large scale with this system of farming except when two or more wheat failures occur in succession.

* The cover picture shows a 16-foot combine cutting wheat on contour strips on the Soil Conservation Project near Hereford, Texas, in 1937. This wheat is producing about 15 bushels per acre. Wheat blew out on this land in the spring of 1936. Contour lines were surveyed and strips 80 feet wide were contour listed to check wind erosion. Later these strips were planted in milo. Intervening strips were contour listed and fallowed for wheat. By seeding time in September, 1936, moisture had been stored to a depth of 40 inches.

Figure 6. Basin listing on contour conserves water. Originally there was snow on the fied, but it thawed, leaving water in the eight-foot long basins. This picture was taken on the Soil Conservation Project at Syracuse, Nebraska, in 1937. Although no exact figures are available, it is safe to say that there was practically no run-off on this field during the winter months.

When conditions are unfavorable for fall planting of wheat (See Appendix A) following a good crop with ample residues, the land should remain in stubble, be listed on the contour, or at least have a very rough surface during that period when wind erosion is most likely to occur. If wheat is planted and fails, the soil should be listed immediately. If rainfall continues insufficient to provide subsoil moisture in the spring and early summer following either of these conditions, sorghum should be planted as late as possible to insure a cover; but when rainfall is adequate for this period; weed growth should be controlled and wheat seeded in the usual manner. If subsoil moisture should remain deficient following the planting of sorghum, wheat should not be planted. Where residues have disappeared due to drought or severe erosion, and an immature, inadequate sorghum cover is obtained, it may be necessary to repeat the sorghum planting the following spring. If rainfall and residues continue to be deficient, wheat should be omitted again and this process repeated each year until conditions are favorable for seeding wheat.

This system of cropping, combined with livestock farming, may be a possible method by which the farmer may become self-supporting and control wind erosion. In suggesting this plan, it is intended that all of the sorghum should be stored for utilization on the farm, regardless of the success of the crop. Then, if the herd and the total acres of land under cultivation are properly adjusted to meet the needs of the family, the good crops should aid materially in supplying reserve feed for the livestock during failures and droughts of short duration.

Figure 7. Harvesting wheat with a 20-foot combine on a field which is contour strip-cropped with alternat strips of wheat and summer fallow on the Soil Conservation Project near Liberal, Kansas, in 1937. This wheat is being produced on summer fallow land which was tilled on the contour in 1936. Note the uniform stand of wheat due to the even distribution of the moisture. Broad base terraces were constructed in this field when the wheat was growing.

APPENDIX A

A Proposed Method of Estimating Probable Wheat Production in Northwestern Oklahoma

The value of climatic data in agriculture can be obtained only from an application of probabilities calculated from past records. This appendix compares rainfall data and wheat-yield data for northwestern Oklahoma over a period of years, and suggests the possibility of forecasting the probable yield of wheat in a particular season on the basis of the moisture available at planting time.

Table I shows a comparison of average total rainfall and wheat yields by seasons from 1924 to 1936, inclusive. The information on precipitation was secured from the Weather Bureau[44] and tabulations on crop production from the Bureau of Agricultural Economics.[1] Various investigators[10 24 44] have shown that the majority of the rain falls from April to October, inclusive, and that a large portion of it occurs between time of harvest and the planting of the next wheat crop. Growing conditions and cropping practices in the extreme High Plains are considerably different from those in the rest of the area. Owing to this situation, the information reported will be discussed under two divisions, Regions I and II, as outlined by Kiltz and others.[24] Although many rains are torrential in character and there was a considerable variation between the different stations in each region, the average rainfall should give some rather general information when compared with the average estimated wheat yields.

TABLE I.—A Comparison of the Average Total Rainfall and Wheat Yields During Different Seasons; Northwestern Oklahoma; 1924 to 1936, Inclusive.

REGION I

Cimarron, Beaver, and Texas Counties[1]

Year	TOTAL RAINFALL				Wheat Yields[4] (Bu.)
		Previous Years			
	July 1 to June 30[3]	June 1 to Oct. 31	June 1 to Sept. 30	July 1 to Sept. 30	
1926	23.6	13.4	12.8	11.1	17.33
1931	20.8	14.2	9.0	7.0	17.03
1928	26.4	14.9	14.1	11.4	14.63
1929	18.5	12.2	9.0	5.6	12.67
1924	23.1	19.5	12.8	7.9	11.70
1932	18.5	7.2	6.3	5.3	6.43
1930	16.5	9.4	8.5	7.0	5.07
1925	13.3	7.5	6.2	5.6	3.53
1934	14.1	8.0	7.3	6.5	2.83
1927	11.5	8.3	8.2	4.8	1.40
1936	12.3	5.6	5.0	3.5	0.77
1935	13.0	7.9	6.9	5.4	0.43
1933	9.2	8.6	8.0	3.6	0.14
Ave.	17.0	10.5	8.8	6.5	7.23

TABLE I.—(Continued.)

REGION II

Alfalfa, Blaine, Custer, Dewey, Ellis, Harper, Roger Mills, Woodward, Woods, and Major Counties[2]

Year	TOTAL RAINFALL				Wheat Yields[4] (Bu.)
		Previous Years			
	July 1 to June 30[3]	June 1 to Oct. 31	June 1 to Sept. 30	July 1 to Sept. 30	
1926	24.1	13.3	11.8	8.7	16.40
1931	22.8	9.4	6.5	3.4	15.30
1924	31.0	24.6	16.0	11.4	14.27
1928	29.0	16.8	15.5	11.6	12.37
1929	27.3	13.7	11.5	6.0	10.70
1932	27.8	9.8	11.2	5.8	10.40
1930	27.6	12.6	8.5	7.8	9.83
1927	32.4	20.3	15.6	12.6	8.61
1934	24.5	10.0	8.4	8.1	7.31
1933	15.6	14.6	13.4	6.0	7.17
1925	24.8	13.2	11.2	9.2	6.58
1936	19.8	9.3	7.5	4.9	5.94
1935	22.7	10.6	9.8	6.3	5.93
Ave.	25..3	13.7	11.3	7.8	10.06

[1] Rainfall data were accumulated at Kenton, Boise City, Goodwell, Hooker, and Beaver.

[2] Rainfall data were accumulated at Cherokee, Canton, Geary, Okeene, Arapaho, Weatherford, Carnegie, Oakwood, Arnett, Buffalo, Cheyenne, Hammon, Mutual, Supply, Woodward, and Alva.

[3] Rainfall from July 1 before seeding time to June 30 the year of harvest.

[4] Average wheat yields based on planted acres estimated by Blood.[1]

In the Panhandle counties listed as Region I, the annual rainfall (from July 1 to June 30 of the following year) varied from 9.2 to 26.4 inches, with an average of 17.0 inches during the period from 1924 to 1936, inclusive. The wheat yields for this period ranged from 0.14 to 17.33 bushels per acre, with an average of 7.23 bushels. Even though there was some variation between the wheat yields and annual precipitation, the lowest yields were secured during dry years.

In order to determine the importance of summer rainfall on wheat yields obtained the following year, the rains from June 1 to October 31, June 1 to September 30, and July 1 to September 30 were also studied. The records in general show that summer rainfall is the outstanding factor in determining crop yields the following year. With only a few exceptions, wheat yields were low, when summer moisture was below average. Since rains in the Panhandle usually fall as local showers, it might be difficult to apply these data to an individual farm. The information shows, however, that unless summer precipitation is favorable, chances for making a wheat crop the next season are greatly limited. When small areas receive an abundance of moisture, crop yields in these localities may often be lower than if the same quantity of water had appeared in general rains, owing to high evaporation losses to the dry atmosphere of the surrounding country.

Region II included Alfalfa, Blaine, Custer, Dewey, Ellis, Harper, Roger Mills, Woodward, Major and Woods counties. Wheat yields in this area are not as closely correlated with rainfall as they are in the Panhandle. The elevation of the land is considerably lower and the distribution of rainfall is different from that in Region I. The average total precipitation from July 1, before the seeding time for wheat, to June 30 the following season was 25.3 inches, while that of the Panhandle was 17.00 inches. Summer rainfall from June 1 to October 31 in Region II was 13.7 inches and in Region I it was 10.5 inches. Even though Region II received a more uniform distribution of moisture during the winter and spring months (with th exception of 1931), summer rainfall seems to be an important factor in wheat production. In only one season during the 13 years (1931) was a high yield of wheat produced when precipitation was below the average for all periods studied. In that year, however, there was a rather uniform distribution of moisture throughout the entire season.

The available information thus indicates that if summer rainfall is low the only hope for a profitable wheat crop the next year is winter moisture, which does not often occur in western Oklahoma. There were, however, some wide variations between rainfall and wheat yields during the different seasons, which seems to indicate that other factors, such as available nutrients, may also influence plant development in this area.

Since summer rainfall is one of the important factors in determining wheat production, these compilations seem to agree with information reported by Hallsted and Mathews[22] showing that the depth to which a soil is wet at seeding time was closely related to the yield obtained. Finnell[15] studied wheat production possibilities in the Panhandle and found that yields the following season were closely associated with soil moisture to a depth of three feet, nitrate nitrogen in surface soil, raw organic matter[14] present at seeding time, and total July rainfall. The dividing point between favorable and unfavorable indications as calculated by Finnell was 2.66 inches of July rainfall, 16.53 percent of deep soil moisture, 19.6 pounds of nitrate nitrogen, and 1312 pounds of unrotted residue per acre in the surface soil of Richfield silt loam. He states that at least three of these initial conditions must be favorable to give some assurance of more than the average yield of wheat.

Finnell's[15] report on the estimation of wheat production possibilities in the Panhandle of Oklahoma was made in 1933. His data are brought up to date in Table II, which gives the forecasted and actual yields of wheat obtained during the past four years. The error of estimate based on Finnell's calculations was 313 pounds of grain per acre where the extreme variation in acre yields noted was 2500 pounds. These records show that the forecasted yield has been within error of estimate except on plats 1306 and 1314 in 1937. The estimated yield based on four initial factors at planting time was 401 pounds per acre on the former and 351 on the latter. Although these plats did not make any grain, they, together with plat 1313, produced enough vegetative growth to prevent soil blowing. The different cultural treatments influenced the yield considerably, but the average of all plats shows that the forecasted yield made in October has been reliable. The average difference in estimated and actual yield varied from 21 to 182 pounds of grain per acre. The past four years, however, have been very dry, and the accuracy of these factors in forecasting wheat yields has not been determined during a season of more than normal rainfall.

TABLE II.—Forecasted* and Actual Yields of Wheat From 1934 to 1937, Inclusive; Goodwell, Oklahoma.

Plat No.	Kind of Crop	Plat Cultural Schedule	Kind of Crop	YIELD 1934 Fore-casted	1934 Actual	1935 Fore-casted	1935 Actual	1936 Fore-casted	1936 Actual	1937 Fore-casted	1937 Actual
1303	Wheat	Stubble early plowed; level tilled and seeded to:	Wheat	—125	48	66	22	—319	000	—197	000
1304	Wheat	Stubble fall plowed and shallow tilled through:	Fallow	211	34	Fallow		—185	000	Fallow	
1305	Fallow	Shallow tilled and seeded to:	Wheat	Fallow		390	148	Fallow		38	000
1906	Wheat	Stubble through winter to:	Fallow	345	223	Fallow		Fallow		401	000
1307	Fallow	Spring plowed, shallow tilled through:	Fallow	Fallow		228	129	Fallow		Fallow	
1308	Fallow	Shallow tilled and seeded to:	Wheat	Fallow		Fallow		119	000	Fallow	
1311	Wheat	Stubble early listed, cultivated to level and seeded to:	Wheat	219	144	259	27	318	000	195	000
1312	Wheat	Stubble fall listed to:	Fallow	325	31	Fallow		—139	000	Fallow	
1313	Fallow	Cultivated to level and seeded to:	Wheat	Fallow		447	427	Fallow		304	000
1314	Wheat	Stubble through winter to:	Fallow	580	500	Fallow		Fallow		351	000
1315	Fallow	Spring listed, cultivated to level through:	Fallow	Fallow		356	289	Fallow		Fallow	
1316	Fallow	Shallow tilled and seeded to:	Wheat	Fallow		Fallow		333	000	Fallow	
Average				259	163	269	174	21	000	182	000

* Based on soil moisture to depth of 3 feet at seeding time, surface nitrate nitrogen and raw organic matter at seeding time, and July rainfall. A detailed procedure was reported by Finnell.[15]

APPENDIX B

Comparison of Rainfall and Evaporation of Water from Open Metal Tanks.

Considerable data[2 3 26 38 43 45] have been published on the seasonal and cyclic variations of precipitation and temperature, but little information is available concerning the relation of rainfall to evaporation from a free water surface in Oklahoma. Holzman[23] reported that approximately one-fourth of the total precipitation on continents has been recognized as run-off returning to the seas and three-fourths as the quantity evaporated into the atmosphere. In considering the relation of precipitation to crop production, the loss of moisture by evaporation from the soil and by transpiration from plants is of much importance, especially in a semi-arid country. The rate of this loss depends largely on the type of soil, climatic conditions, kind of vegetation, and cultural procedure. Over the Great Plains region, the amount of evaporation from a free water surface is much greater in the South than in the North. The agricultural importance of these differences, in terms of actual equivalent rainfall, can be determined only approximately, but some investigators[27] have shown that for effectiveness in plant growth 15 inches of annual rainfall in North Dakota are equivalent to about 25 inches in Texas.

Thornthwaite[42] states that the relation of precipitation to evaporation is probably the most significant climatic factor from the standpoint of agriculture, but that its determination is extremely difficult because present methods of measuring these constituents are grossly inadequate. He also states that "measurements of evaporation are even less satisfactory than those of precipitation, and there is at present no indication that any direct means of determining the actual amount of water lost through evaporation will be found."

Although present instruments for measuring these constituents may not be adequate, calculations were made from the only available data for Oklahoma in order to give their approximate relation. These records were obtained from the Agricultural Experiment Station, Stillwater, Oklahoma; Soil Conservation Experiment Station, Guthrie; Dry Land Agricultural Experiment Stations at Lawton and Woodward; and Panhandle Agricultural Experiment Station, Goodwell. Since evaporation losses have not been recorded in eastern Oklahoma, information was secured from Weather Bureau stations at Stuttgart and Russellville, Ark.

This information was not all obtained by a uniform method, and the data are therefore not directly comparable. Daily observations on evaporation at Lawton, Woodward, and Goodwell were made by measuring the depth of water in cylindrical metal tanks 6 feet in diameter and 2 feet deep, placed at a depth of 20 inches in the ground with the water level maintained at or below the surface of the soil. Cylindrical pans 4 feet in diameter were used at Stuttgart and Russellville, Ark., and at Stillwater and Guthrie, Oklahoma. These pans varied from 10 to 20 inches in depth and rested on a wooden frame with the bottom about 6 inches above the surface of the ground. Rainfall was collected at all stations in standard gauges as recommended by the United States Weather Bureau. Owing to low evaporation in cold weather and the inaccuracy of measurments introduced by freezing, a complete record for 12 months is not available at all stations.

The warm season evaporation and rainfall from April to September, inclusive, are compared in Table III. The average quantity of water in inches evaporated from a free surface at the different locations was as follows: Stuttgart, 41.19; Stillwater, 61.28; Guthrie, 59.43; Lawton, 45.57;

TABLE III.—The Total Inches of Rainfall and Evaporation from Open Metal Tanks During the Warm Season (April to September, Inclusive).

Year	STUTTGART ARK.		STILLWATER		GUTHRIE		LAWTON		WOODWARD		GOODWELL	
	Rainfall	Evaporation	Rainfall	Evaporation	Rainfall	Evaporation	Rainfall	Evaporation	Rainfall	Evaporation	Rainfall	Evaporation
1914									10.54	52.57		
1915									26.75	41.66		
1916							15.97	46.72	17.10	53.93		
1917							13.37	51.03	14.48	50.87		
1918							14.96	52.40	11.45	49.78		
1919							21.76	37.02	14.46	45.32		
1920							19.47	38.33	18.45	48.49		
1921							15.28	38.75	20.04	50.61		
1922							20.14	39.56	13.31	58.31		
1923							19.75	42.23	25.04	49.11		
1924							16.44	43.52	15.07	49.22		
1925							21.69	48.69	12.15	50.95	13.85	53.59
1926							21.46	42.64	17.78	47.77	14.71	42.91
1927							19.86	42.23	18.61	46.10	15.34	49.18
1928							16.84	40.68	14.59	50.48	16.59	46.33
1929							22.10	43.54	14.46	50.80	12.91	49.43
1930	16.20	49.63					15.12	48.12	16.05	57.84	12.93	52.39
1931	18.40	41.13					10.77	45.63	13.91	52.98	10.55	46.69
1932	15.90	42.22	25.29	58.07			17.30	43.11	20.63	52.13	10.59	48.47
1933	31.88	35.24	15.20	62.97			19.84	49.65	12.14	57.28	9.53	57.76
1934	19.73	44.92	17.17	71.40	24.97	64.98	11.06	57.85	13.58	61.71	9.27	56.67
1935	23.02	36.10	20.11	50.65	19.46	47.78	16.62	43.95	11.60	50.12	8.27	51.14
1936	17.39	44.00	13.95	68.48	17.73	69.64	19.64	56.51	12.48	57.21	7.84	50.36
1937	21.60	36.30	18.94	56.12	16.87	55.34	19.26	50.43	11.23	55.43	9.12	50.36
Average	20.51	41.19	18.44	61.28	19.76	59.43	17.67	45.57	15.66	51.69	11.65	50.41

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Woodward, 51.69; Goodwell, 50.41. The average rainfall in inches for the same period at these stations was 20.51, 18.44, 19.76, 17.67, 15.66 and 11.65, respectively. The highest average evaporation was at Stillwater and Guthrie, and the lowest at Stuttgart and Lawton. Data from Arkansas were accumulated at the Rice Agricultural Experiment Station. Rainfall there is high; and wind velocity, humidity, and temperature differ considerably from those at the other stations. Since evaporation measurements in central Oklahoma and Arkansas were taken from small tanks placed above the ground, some of the differences in water lost may be due to the method of observation. However, both procedures for measuring evaporation[25] [39] are used by different divisions of the United States Department of Agriculture to obtain an estimate of the amount of water removed from a tank exposed to the direct rays of the sun and unprotected from wind. The greatest amount of evaporation for a particular season was 71.40 inches, occurring in 1934 at Stillwater. The lowest value was 35.24 inches, recorded at Stuttgart in 1933.

The average total inches of water evaporated per month, and data on rainfall, are recorded in Tables IVa to IVc. Since some stations determined evaporation losses for the warm season only, records are not available for the winter months at all places. Measurements for each month in the year were secured at Stillwater from 1932 to 1936, and throughout the entire year at Stuttgart, Russellville and Goodwell. This information was also obtained during some of the cool and cold season months at Lawton and Woodward, but complete monthly data were not collected. Although considerable monthly variation occurred, the loss of water from metal tanks was highest in July and lowest in December and January. The highest average amount of evaporation took place during June, July, and August at all stations. The greatest quantity of water lost in a particular month was 17.70 and 17.67 inches. This occurred in July 1934 at Stillwater and Guthrie, respectively.

The distribution of rainfall during the year is not the same at all locations, and it is difficult to make any comparisons of tabulations obtained. In Arkansas a high percentage of the total precipitation comes in winter, and the summer months receive a small portion of the total. The average quantity of rainfall during the warm season is higher than that recorded in central and western Oklahoma, where most of it falls in the summer months. The average annual precipitation at the different stations by areas is as follows: Arkansas, 52.31 inches; central Oklahoma, 29.98 inches; western Oklahoma, 21.41 inches. The average annual evaporation was 57.34, 80.90, and 68.64 inches, respectively.

The evaporation-rainfall ratios for various months of the year calculated for the different stations were greatest during the warm season at all stations except Goodwell. The average annual evaporation-rainfall ratio for the Arkansas locations was 1.10; for central Oklahoma, 2.70; for western Oklahoma, 3.21. The warm season evaporation-rainfall ratio for these locations was 1.84, 3.16 and 3.28, respectively. These general tabulations show that, when other conditions are similar, the rate of evaporation increases as rainfall decreases. This information seems to agree with that published by Coles and Wagner[5] showing that high evaporation is usually associated with low rainfall. According to Kincer [25], the rate of evaporation from soil is affected by the soil texture, temperature, wind movement, and humidity of the atmosphere. Finnell[11] states that "high wind and low humidity are associated, but temperature varies independently". Therefore, evaporation may be accelerated in central Oklahoma because of high temperature [40] [44] occurring in the area.

Compilations obtained from Arkansas cannot be used to show the exact condition prevailing in eastern Oklahoma, but an average figure

TABLE IVa.—Average Total Inches per Month of Rainfall; Evaporation of Water from Open Metal Tanks; and the Ratio Between the Two—Stuttgart and Russellville, Arkansas.

	STUTTGART (8 YRS.)		RUSSELLVILLE (1 YR.)		AVERAGE		Ratio: Evaporation ÷ Rainfall
	Evaporation	Rainfall	Evaporation	Rainfall	Evaporation	Rainfall	
January	1.26	7.36	1.09	9.94	1.17	8.65	0.13
February	1.89	3.81	2.73	1.83	2.31	2.82	0.82
March	3.66	4.37	3.73	3.50	3.69	3.93	0.94
April	5.07	2.70	6.07	2.80	5.57	2.75	2.02
May	6.38	5.68	7.31	5.89	6.84	5.78	1.18
June	8.09	2.87	8.27	4.01	8.18	3.44	2.38
July	8.15	4.77	9.06	3.42	8.60	4.09	2.10
August	7.93	1.89	8.46	3.13	8.19	2.51	3.26
September	5.58	2.60	5.17	6.77	5.37	4.68	1.15
October	4.02	2.84	3.48	5.22	3.75	4.03	0.93
November	2.38	5.04	2.42	2.61	2.40	3.82	0.63
December	1.13	6.33	1.41	5.30	1.27	5.81	0.22
Total	55.54	50.26	59.20	54.42	57.34	52.31	
Ratio: Evaporation ÷ Rainfall							
Annual	1.11		1.09		1.10		
Warm season[1]	2.00		1.70		1.84		

[1] April to September inclusive.

TABLE IVb.—Average Total Inches per Month of Rainfall; Evaporation of Water from Open Metal Tanks; and the Ratio Between the Two—Stillwater and Guthrie, Oklahoma. (Central Oklahoma.)

	STILLWATER (6 YRS.)		GUTHRIE (4 YRS.)		AVERAGE		Ratio: Evaporation ÷ Rainfall
	Evaporation[1]	Rainfall	Evaporation	Rainfall	Evaporation	Rainfall	
January	2.10	1.29			2.10	1.29	1.63
February	2.37	1.05			2.37	1.05	2.26
March	5.73	1.58			5.73	1.58	3.63
April	8.34	1.64	7.55	2.20	7.94	1.92	4.13
May	7.97	2.81	7.34	3.69	7.65	3.25	2.35
June	11.53	4.30	10.64	3.57	11.08	3.93	2.82
July	13.61	2.82	14.27	0.56	13.94	1.69	8.25
August	12.51	3.36	13.47	3.78	12.99	3.57	3.64
September	7.26	3.51	6.15	5.95	6.70	4.73	1.42
October	5.52	2.52	4.41	2.02	4.96	2.27	2.18
November	3.15	2.86			3.15	2.86	1.10
December	2.29	1.84			2.29	1.84	1.24
Total	82.38	29.58	63.83	21.77	80.90	29.98	
Ratio: Evaporation ÷ Rainfall							
Annual	2.78		2.93		2.70		
Warm season[2]	3.32		3.01		3.16		

[1] Average of 4 years for January and February.
[2] April to September inclusive.

TABLE IVc.—Average Total Inches per Month of Rainfall; Evaporation of Water from Open Metal Tanks; and the Ratio Between the Two—Lawton, Woodward and Goodwell, Oklahoma. (Western Oklahoma.)

	LAWTON (22 YRS.)		WOODWARD (24 YRS.)		GOODWELL (13 YRS.)		AVERAGE		Ratio: Evaporation÷Rainfall
	Evaporation[1]	Rainfall	Evaporation[2]	Rainfall	Evaporation[3]	Rainfall	Evaporation	Rainfall	
January									
February			3.55	0.64	1.69	0.25	1.69	0.25	6.76
March	4.84	1.59	6.62	1.45	2.45	0.51	3.00	0.57	5.26
April	5.72	2.75	6.44	2.18	4.39	0.83	5.28	1.29	4.09
May	6.50	4.38	7.37	3.48	6.16	1.13	6.11	2.02	3.02
June	8.20	2.83	9.57	2.97	7.36	2.55	7.08	3.47	2.04
July	9.50	2.40	11.08	1.83	9.56	2.15	9.11	2.65	3.44
August	9.12	2.19	9.80	2.45	10.66	2.23	10.41	2.15	4.84
September	6.54	3.12	7.43	2.75	9.47	2.02	9.46	2.22	4.26
October	4.62	3.91	4.96	2.30	7.20	1.57	7.06	2.48	2.85
November	2.79	1.64	2.91	1.44	4.90	1.19	4.83	2.47	1.96
December			1.99	0.70	2.76	0.76	2.82	1.28	2.20
					1.60	0.42	1.79	0.56	3.20
Total	57.83	24.81	71.72	22.19	68.20	15.61	68.64	21.41	
Ratio: Evaporation÷Rainfall									
Annual	2.33		3.23		4.37		3.21		
Warm season[4]	2.58		3.30		4.33		3.28		

[1] Average of 16 years for March and 20 years for November.
[2] February, March and December, one year only; average of 5 years for October and 3 years for November.
[3] During wind storms, drifting soil often collected in the tank; but this error was corrected to as great an extent as possible.
[4] April to September inclusive.

Figure 8. A typical farm pond of central and western Oklahoma.

calculated from these records and from information recorded at Stillwater and Guthrie should give a general idea of the relation of evaporation to rainfall in that part of the State. When such calculations were made, the annual evaporation-rainfall ratio was 1.68 and the warm season ratio was 2.76. The average evaporation-rainfall ratio for different months and seasons varied from 0.13 to 3.26 in Arkansas and from 1.10 to 4.84 in Oklahoma. At Goodwell, where rainfall is low, the average annual evaporation was 4.37 times greater than precipitation. A similar ratio calculated for the warm season was 4.33. During the 13-year period, the warm season ratio has varied from 2.79 to 6.42. The years from 1933 to 1937 were seasons of low rainfall accompanied by high evaporation, and the ratio between these constituents during these years was 6.06, 6.11, 6.18, 6.42 and 5.52, respectively. There was considerable variation between the different seasons, but calculations show an average annual loss of 6.23 feet of water from a free water surface in central and western Oklahoma. Farm ponds (Figure 8) or large lakes that are constructed in this area to supply water for animals or irrigation must have a capacity equivalent to the supply needed plus amount removed by evaporation plus an additional depth, depending upon soil conditions, which may be lost by seepage.

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